Identification of unusual weather states causing heavy areal precipitation in West Africa

J. Bliefernicht[1], P. Laux[2] and H. Kunstmann[1,2]

1: University Augsburg, Chair for Regional Climate and Hydrology, Germany

2: Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research, Germany

contact: Jan.Bliefernicht@geo.uni-augsburg.de

Motivation

Precipitation extremes are often caused by unusual weather states. The identification of unusual weather states therefore is a basic prerequisite for downscaling and forecasting hydro-meteorological extremes. Recently, a promising technique has been proposed for the identification of unusual weather states based on the notion of data depth. This technique is used to measure the centrality of a weather state. The less central a given weather state is, the less frequent the state is and the more unusual this weather state becomes. In this investigation we test the methodology for the identification of unusual states which can cause large-area long-lasting heavy precipitation in West Africa. The following issues are highlighted in this presentation in detail:

- The basic idea of this new concept for the identification of unusual weather states is illustrated.
- It is demonstrated that there is a link between precipitation and pressure related variables even during the rainy season.
- The performance of this technique is illustrated using a very simple classification approach based on the daily pressure regime.

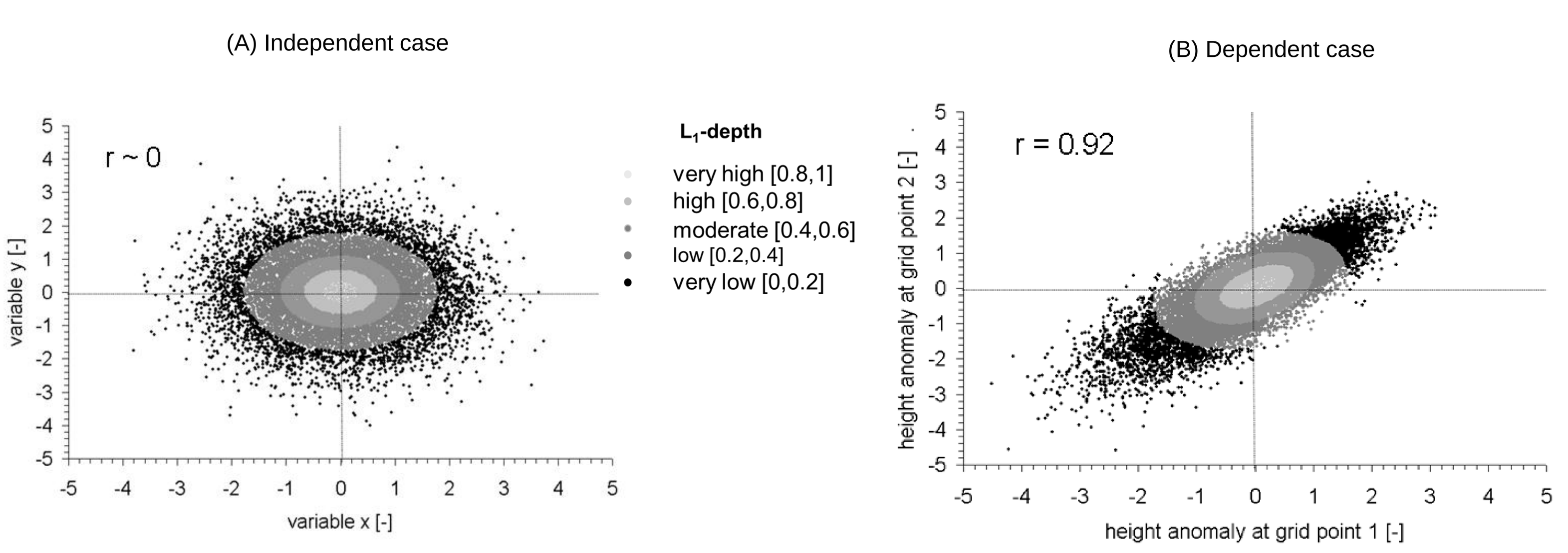
Identification of unusual weather states using the notion of data depth

There are many data depth functions which can be selected to measure the centrality of an atmospheric state (see Liu et al., 1999). In this investigation the L_1-depth is used (Vardi & Zhang, 2001) since this function is easy to calculate in comparison to other depth functions and represents thereby a suitable starting point for an investigation. The L_1-depth of an atmospheric state $\mathbf{x}(t_0) = (x_1, x_2, \ldots, x_k)$ with k dimension at time t_0 can be calculated from a set of n atmospheric states $\mathbf{X} = [\mathbf{x}(t_1), \mathbf{x}(t_2), \ldots, \mathbf{x}(t_n)]$ in the following way:

$$L_1[\mathbf{x}(t_0)] = 1 - \left| \sum_i^n g_i \frac{\mathbf{x}(t_0) - \mathbf{x}(t_i)}{\left|\mathbf{x}(t_0) - \mathbf{x}(t_i)\right|} \right|$$

g_i is the weight of an atmospheric state.

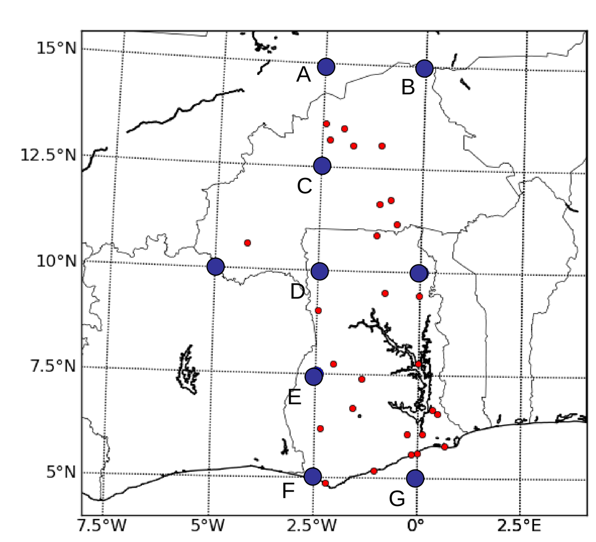
The L_1-depth ranges between zero and one. The lower the centrality of an atmospheric state the larger the data depth becomes. The data depth is largest (one) if the atmospheric state is in the center.

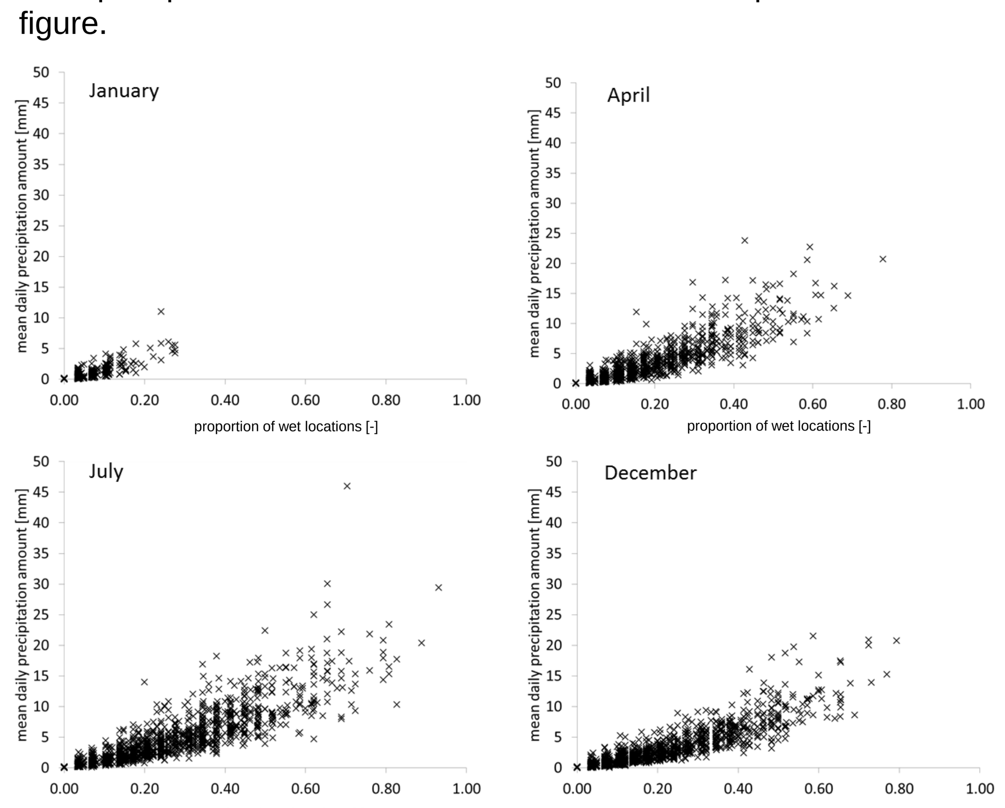


The data depth for data pairs of two independent standard normal distributed variables is illustrated in the left figure. Data pairs near the center have a very high data depth (light grey). Data pairs at the boundary of the data cloud have a very low data depth (black dots). These data pairs are indicated by the L_1-depth as unusual atmospheric states. Many statistical downscaling applications use pressure related variables to describe the atmospheric state over a geographical region. These variables are characterized by a high spatial dependence so that the resulting data cloud is different in comparison to the independent case. For example, the data cloud of two time series of daily height anomalies taken from grid points close to a study region is illustrated in the right figure. In this case, the L_1-depth only identifies those states as unusual if high negative or high positive anomalies occur to the same time at both grid points.

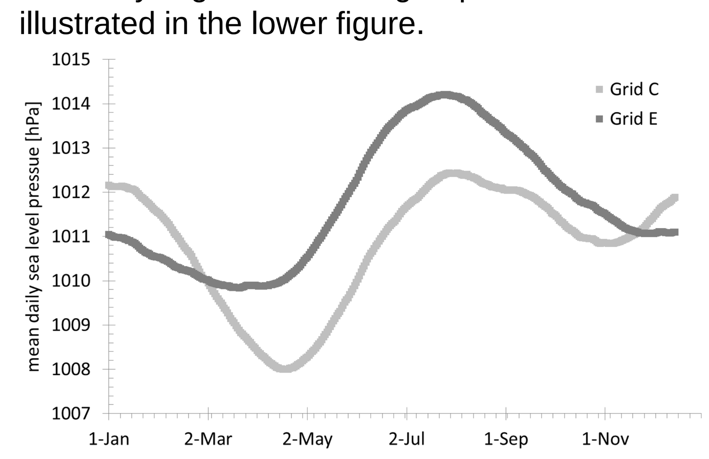
Study region and data

The study region is located in the Volta basin. The investigation period ranges from 1961 to 1999. Large-area long-lasting heavy precipitation is indicated by two indices: the mean daily precipitation amount P_a and the proportion of wet locations in the study region P_1. The mean daily precipitation amount is calculated from daily point observations measured at 29 land surface stations located in Burkina Faso and Ghana. The locations of the stations are indicated as red dots in the map. The proportion of wet locations is the number of precipitation stations with a observed rain event (P > 2 mm/d) divided by the total number of stations. It is a measure that indicates the size of the precipitation area. The indices are calculated for each day of the investigation period. The close relationship between the daily values of both precipitation indices is illustrated as scatter plots in the lower figure.



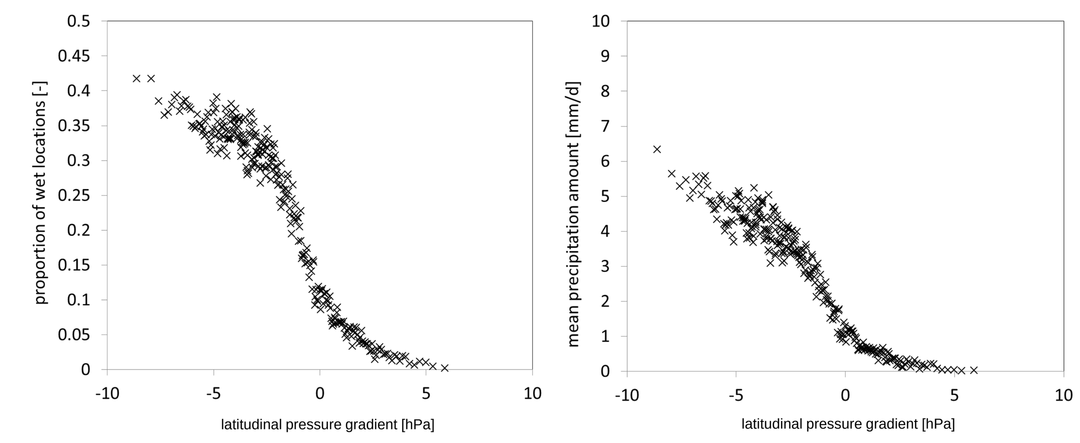


The large-scale atmospheric information used in this study is six-hourly mean sea level pressure (12 UTC) and geopotential height (12 UTC, 850 hPa) taken from grid points which are highlighted in blue in the map. Both variables are part of the data archive of the NCEP/NCAR reanalysis 1. The latitudinal pressure regime for the study region between grid point C and E is illustrated in the lower figure.

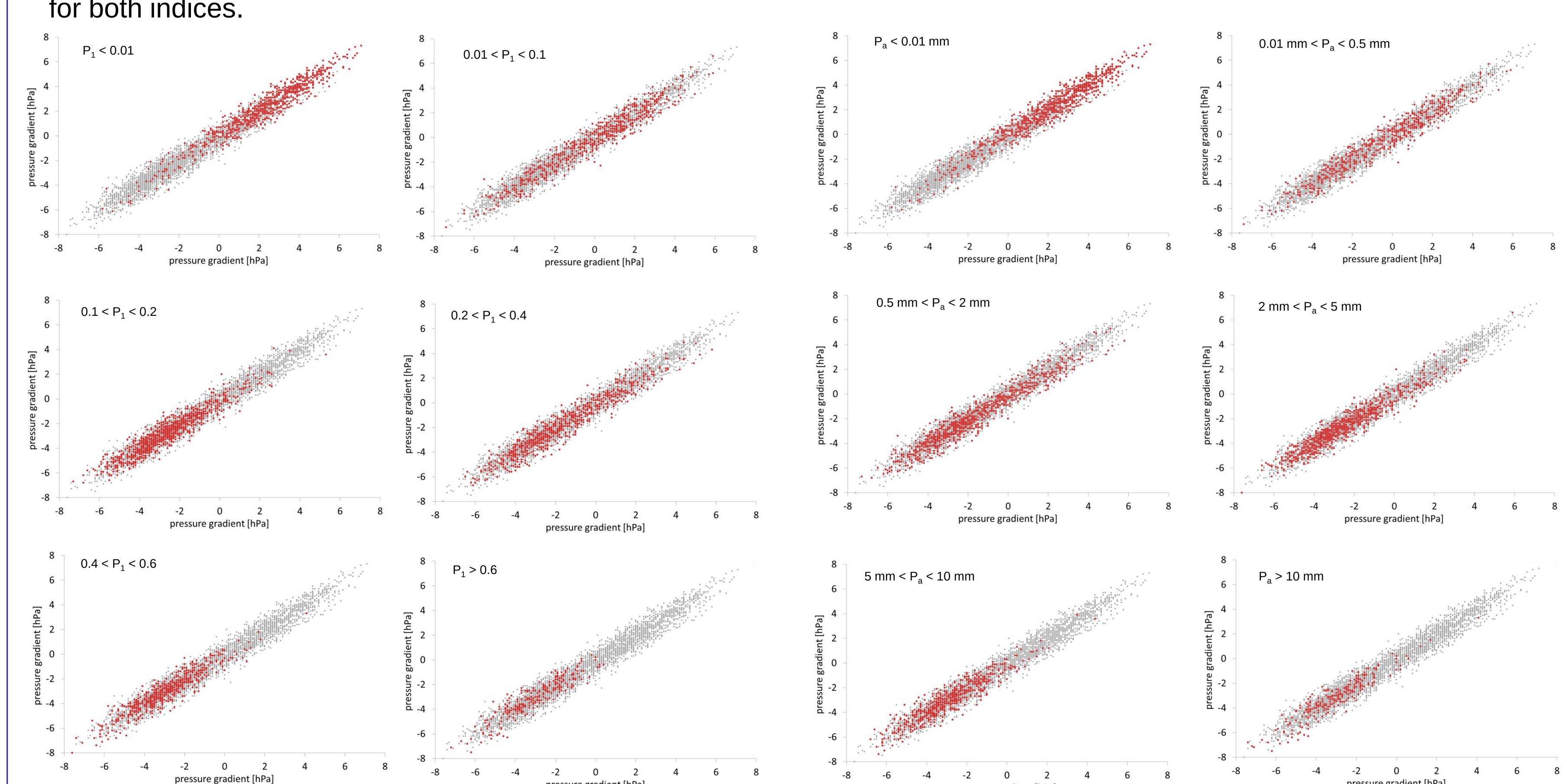


Link between daily sea level pressure and precipitation indices

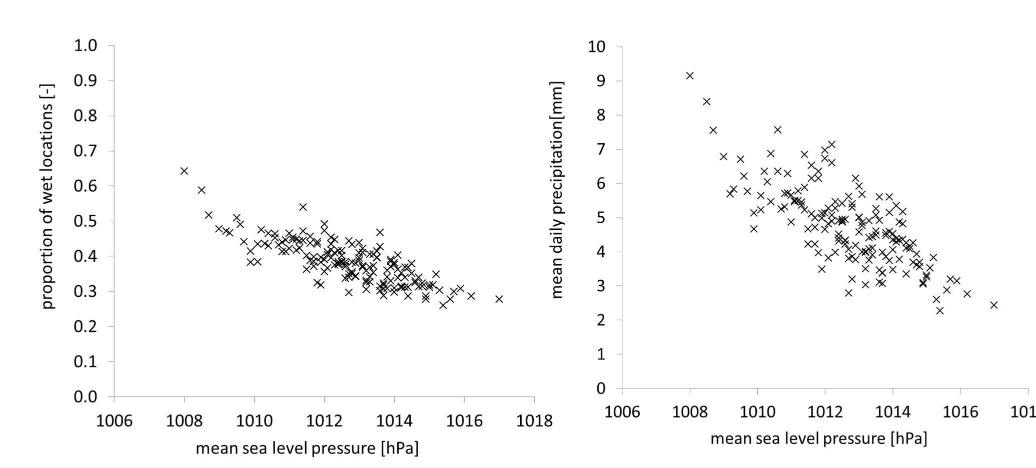
The right figures show that the latitudinal daily pressure gradient Δp_x between two grid point seems to be a good indicator for prediction of both daily indices. We used here the pressure gradient between grid point A and F. There is a clear link between both indices and the gradient so that dry and wet days can be separated for the study region. The reason is a change of the pressure regime when the Intertropical Convergence Zone moves north and south along the study region (see figure below).



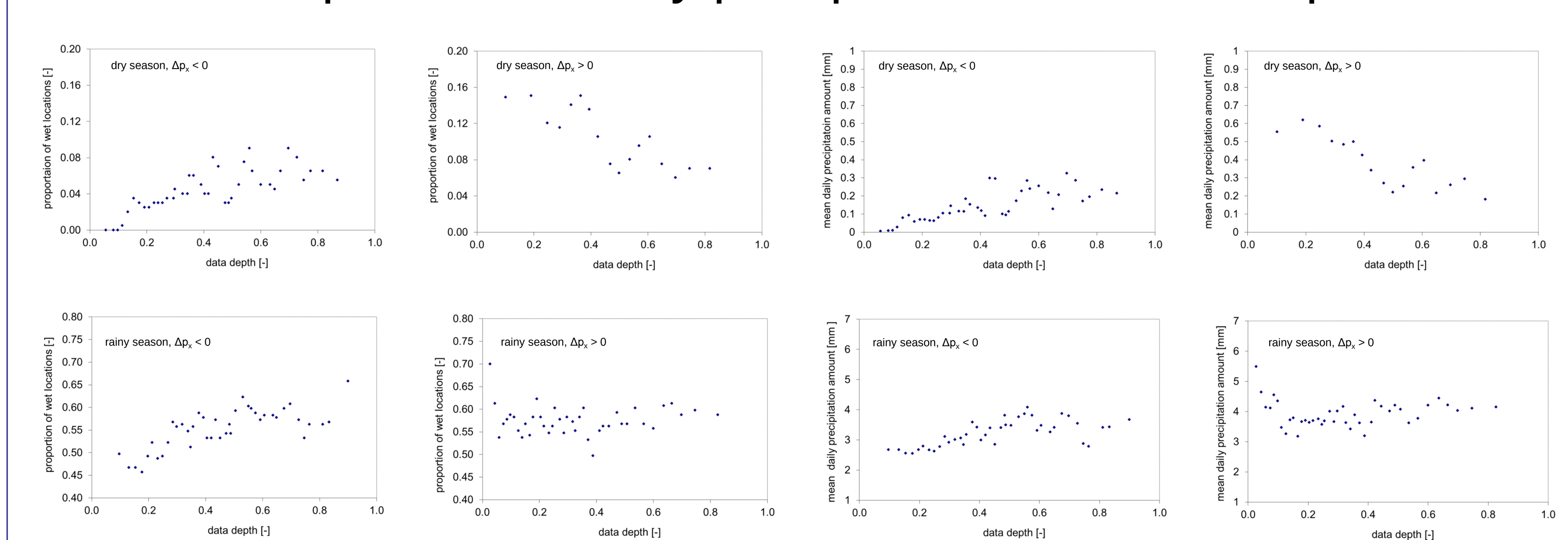
The scatter plot of daily time series for two latitudinal pressure gradients (grid points A-F and B-G) is given in the lower figures for six precipitation categories. The entire data set is illustrated by grey pairs. Highlighted in red are those data pairs which belong to the precipitation category given in the figures. The scatter plots show that there is a clear pattern in the data cloud recognizable for both indices indicating that days with no precipitation can be separated from days with low, moderate and intensive precipitation. However, the pressure gradients seems to be not a good indicator for the prediction of extremes for both indices.



Due the strong annual cycle of the precipitation regime in that region similar results can be easily obtained by separating the data in different months. The question is whether daily precipitation can be also linked to daily pressure related variables during the rainy season. The same analysis was therefore done for the rainy season with the result that the pressure gradient is not a good indicator for the separation (not shown here). In contrast, the mean sea level pressure at grid point D seems to be a good indicator for this period. The observed relationship between mean sea level pressure and both indices is illustrated in the left figure for the data of two months (July and August). The lower the pressure the higher e.g. the mean precipitation amount is.



Relationship between daily precipitation and data depth



The data depth is calculated for two gradients of the geopotential height selected from the same grid point like in the previous investigations (A-F and B-G) . Afterwards, the data is divided into four subsets based on daily pressure regime and monthly precipitation regime to separate dry atmospheric states from wet atmospheric states. The observed relationship between the data depth and the precipitation indices is illustrated in the upper figures for the four subsets. Very dry atmospheric states can be clearly identified by the data depth approach based on this simple classification although only the information of two height gradients is used for the analysis. However, the identification of atmospheric states causing precipitation extremes is still problematic with this simple approach.

Conclusion and future research

We illustrated in this study that there is a clear link between daily precipitation indices and daily pressure related variables, even during the rainy season. If wet and dry atmospheric states are separated from each other, the selected simple approach based on the L_1-depth seems to be a good indicator for the identification of extremely dry days in the Volta basin. To improve the detection of precipitation extremes a more sophisticated approach will be tested e.g. by replacing the current simple classification technique with an approach for an automated classification of daily circulation patterns (Bárdossy et al., 2002). We will also test moisture indices as additional information for the prediction of extreme precipitation. The focus of future studies will be also the illustration of the downscaling performance based on standard skill scores used in forecast verification.

This work is part of the Core Research Program of WASCAL (West African Science Service Center on Climate Change and Adapted Land Use) which is funded by the German Ministry of Education and Research (BMBF). The precipitation data was kindly provided by the national meteorological and hydrological services during the GLOWA-Volta project.

Bárdossy, A.; Stehlík, J. & Caspary H. 2002. Automated objective classification of daily circulation patterns for precipitation and temperature downscaling based on optimized fuzzy rules. Clim. Res, 2002, 23, 11-22

Liu, R., Parelius, J., and Singh, K.: Multivariate analysis by data depth: descriptive statistics, graphics and inference, Annals of statistics, pp. 783-840, 1999.

Vardi, Y. and Zhang, C.: The multivariate L1-median and associated data depth, 2000.